

TRANSESTERIFICATION CHEMISTRY. LOW TEMPERATURE REACTIONS OF O-NITROPHENYL CARBONATES

Daniel J. Brunelle

General Electric Research and Development Center
P.O. Box 8, Schenectady, New York, 12301, USA

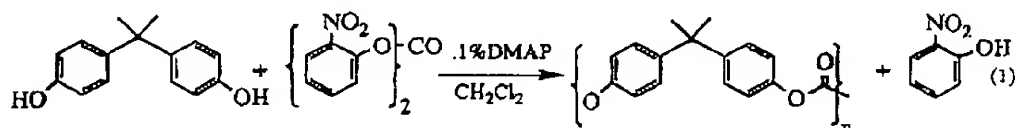
ABSTRACT: The application of o-nitrophenyl carbonate to preparation of aromatic carbonates and polycarbonates is described. The differences in reactivity of *ortho*- and *para*-nitrophenyl carbonates are elaborated. Reaction of o-nitrophenyl carbonate, bisphenol, and catalytic nucleophilic base affords clean formation of polycarbonates via transesterification at or below ambient temperatures.

INTRODUCTION

The preparation of polycarbonates via transesterification reactions using diphenyl carbonate are well known, having been first reported in 1964.¹ Typically, polycarbonate is prepared by heating a bisphenol with a slight excess of diphenylcarbonate in the presence of catalyst to 280-300° C, while removing by-product phenol via vacuum distillation. Although tough, high molecular weight bisphenol A polycarbonate can be prepared via the transesterification pathway, the reaction has traditionally been fraught with difficulties (color formation, thermal degradation, high hydroxyl chain termini, presence of residual catalyst, etc.) Although mild catalysts for these reactions have been developed,² the effects of long duration, high temperature reactions are difficult to overcome. Thus, we became interested in a phosgene equivalent which would permit preparation of polycarbonate by transesterification at significantly reduced temperatures.

Carboxylic acid esters of p-nitrophenol, 2,4-dinitrophenol, and 2,4,6-trichlorophenol are often used as activated substrates for ester exchange reactions.³ p-Nitrophenyl esters are commonly used as activated substrates in peptide synthesis, due to the fact that p-nitrophenol is a good leaving group.⁴ o-Nitrophenyl esters and carbonates have received little attention in transesterification reactions, since o-nitrophenol is less acidic than p-nitrophenol (pKa's 7.23 and 7.15, respectively⁵), and hence less reactive, both due to steric hindrance and decreased leaving group ability. Hydrolysis studies of nitrophenyl benzoates⁶ support these reactivity estimates. The only prior report of *dis*-(o-nitrophenyl) carbonate (o-NPC) concerns preparation of dialkyl carbamates from reaction of o- or m-nitrophenyl carbonates with secondary amines.

A preliminary paper reported that *o*-NPC was extremely reactive toward transesterification in the presence of certain catalysts. Thus, reaction of *o*-NPC with phenol at ambient temperature in CH_2Cl_2 using 0.01 eq of 4-dimethylaminopyridine (DMAP) affords a quantitative yield of diphenyl carbonate in one hour. This paper reports that high molecular weight polycarbonates are efficiently prepared from *o*-NPC (Equation 1).



RESULTS

The carbonate of *p*-nitrophenol has been used in reactions in alcoholic KOH to prepare mixed carbonates such as methyl *p*-nitrophenyl carbonate; subsequent reaction with an amine forms a urethane. The carbonates of *p*-nitrophenol and of 2,4-dinitrophenol have been used in peptide synthesis applications. All known reactions of nitrophenyl carbonates bear three common features: each requires a full equivalent of base, a mixed carbonate or urethane is isolated from each, and attack by an amine is always involved.

Ortho- and *para*-nitrophenyl carbonates were readily prepared via reaction of the requisite nitrophenol with Et_3N and phosgene. When the use of nitrophenyl carbonates for preparation of aryl carbonates via transesterification using catalytic base was first attempted, only very low yields of product were obtained. Although attack of phenol occurs with displacement of nitrophenol, irreversible formation of nitrophenoxide occurs, removing the base from the catalytic cycle. Thus, a full equivalent of base would be necessary for complete reaction.

Reaction of *p*-nitrophenyl carbonate (*p*-NPC) with two moles each of phenol and triethylamine at 0°C in CH_2Cl_2 afforded diphenyl carbonate in about 50% in 4 hr. *o*-NPC reacts at less than half that rate (Figure 1). DMAP was used in an attempt to enhance the reactivity of the nitrophenyl carbonates. DMAP, although less basic than Et_3N , enhances acylation and hydrolysis of esters by as much as 10^4 relative to pyridine.¹¹ Using 1 eq of Et_3N and 0.01 eq of DMAP, only a slight rate enhancement was noted with *p*-NPC. However, a 42-fold increase in rate was noted when 0.01 eq of DMAP was used with *o*-NPC; a quantitative yield was obtained in 3 hr at 0°C (Figure 1).

Even more surprisingly, it was found that reactions of *o*-NPC with phenols catalyzed by DMAP do *not* require stoichiometric base. No decreases in rate or yield were observed in reactions using 1% molar catalyst in the absence of Et_3N . This is not the case using the *para*-isomer. If no Et_3N is used, the rate of reaction drops by a factor of 17. The use of *o*-NPC in combination with DMAP thus provides a fast, clean reaction to form aromatic carbonates at ambient temperature using only catalytic amine. Results for a variety of catalysts are summarized in Table 1, and examples of aromatic carbonate formation in Table 2. Solvent can have an important effect on the reaction, with low polarity solvents

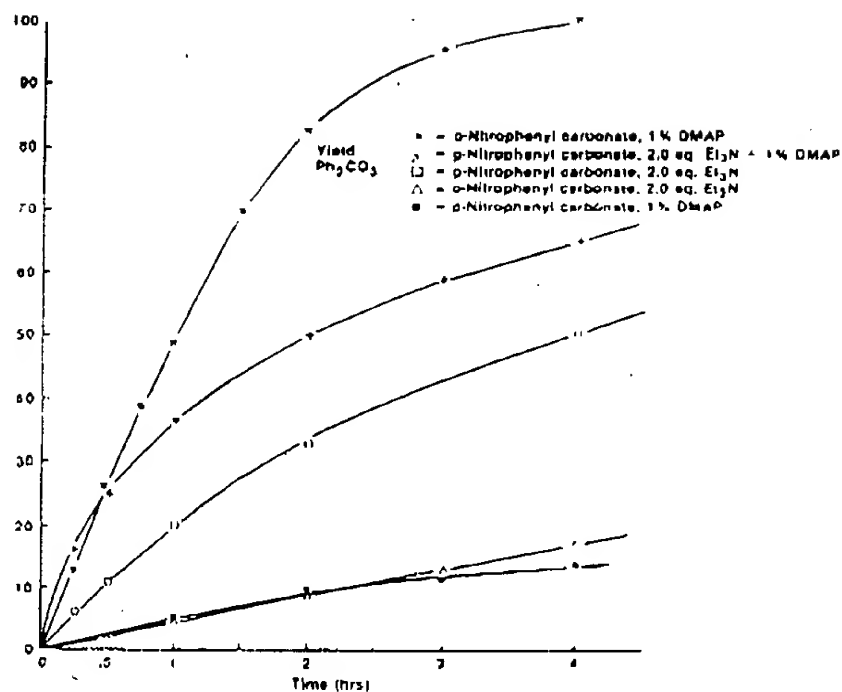


Figure 1. Preparation of Diphenyl Carbonate from Nitrophenyl Carbonates at 0° in CH_2Cl_2

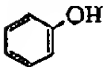
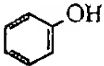
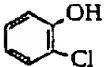
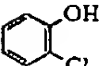
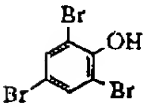
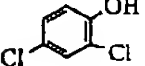
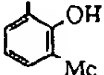
Table 1. Effects of Catalyst on Transesterification of o-Chlorophenol^a

Catalyst	Time(hr)	o-Cl-phenyl Carb. Yield ^b
None	3	0
DMAP	1	99
NaOPh	1	7
NaOPh + Bu_4NBr	1	35
Et_3N	2	5
DABCO	3	0
DBU^c	3	20
DBN^d	3	63
N-Methylimidazole	3	20
4-Pyrrolidinopyridine	1	100

^aReaction with o-NPC in CH_2Cl_2 at 25° C, using 1% molar catalyst.

^bYield by VPC vs n-docosane² internal standard. ^c1,8-Diazabicyclo[5.4.0]-undecane. ^d1,5-Diazabicyclo[4.3.0]nonane.

Table 2. Aryl Carbonate Preparation from o-NPC and p-NPC^a

Phenol	Substrate	Time (hr)	Carbonate Yield
	o-NPC	2	100
	p-NPC	48	52 ^b
	o-NPC	2	99.5
	p-NPC	48	23 ^c
	o-NPC	8	95
	o-NPC	20	92
	o-NPC	24	17 ^d

^aReaction in CH_2Cl_2 at 25° using 1% DMAP. ^b44% mixed carbonate and 4% SM also isolated. ^c55% mixed carbonate and 19% SM obtained. ^d85% mixed carbonate.

such as CH_2Cl_2 , CHCl_3 , toluene, or chlorobenzene being preferred. Polar solvents such as dioxane, THF, or DMF give substantially reduced rates of reaction.

A variety of polycarbonates have been prepared using o-NPC as the transesterification agent. Table 3 lists a summary of results with various bisphenols. Sterically hindered bisphenols such as 3,3',5,5'-tetrabromo- or tetramethyl bisphenol A formed only low molecular weight polymers, indicating that some steric limitations may be operative. In some cases, the polycarbonate formation was somewhat retarded by the sparse solubility of the bisphenols in the reaction solvent (usually CH_2Cl_2). However, as the reaction proceeded, solution occurred, and molecular weight builds steadily; after 1 hr $M_n = 870$, after 4 hr, $M_n = 3900$; after 24 hr, $M_n = 58,000$ using bisphenol A. The polymers of thiodiphenol and sulfonyl diphenol were insoluble under the reaction conditions, and precipitated at medium molecular weights. However, copolymers with bisphenol A were soluble and attained high molecular weights.

Table 3. Polycarbonate Formation via o-Nitrophenyl Carbonate^a

Monomer	Catalyst (Mole%)	Solvent	Time/Temp/Pres. ^b	Mw (x10 ³) ^c
	DMAP (0.1)	CH ₂ Cl ₂	20/25/atm	58
	DMAP (0.1)	none	1/125/atm	24
	NaOPh/Bu ₄ NBr (.2)	none	1/150/atm .25/200/10	77.3
	NaOPh/Bu ₄ NBr (.2)	PhCl ₂	2/150/atm	18
	DMAP (0.1)	CH ₂ Cl ₂	20/25/atm	39
	DMAP (0.2)	CH ₂ Cl ₂	20/25/atm	12
	DMAP (0.2)	CH ₂ Cl ₂	20/25/atm	9
	DMAP (1.0)	CH ₂ Cl ₂	20/25/atm	9
	DMAP (1.0)	CH ₂ Cl ₂	20/25/atm	4
/ BPA	DMAP (0.2)	CH ₂ Cl ₂	20/25/atm	48
/ BPA	DMAP (0.2)	CH ₂ Cl ₂	20/25/atm	29

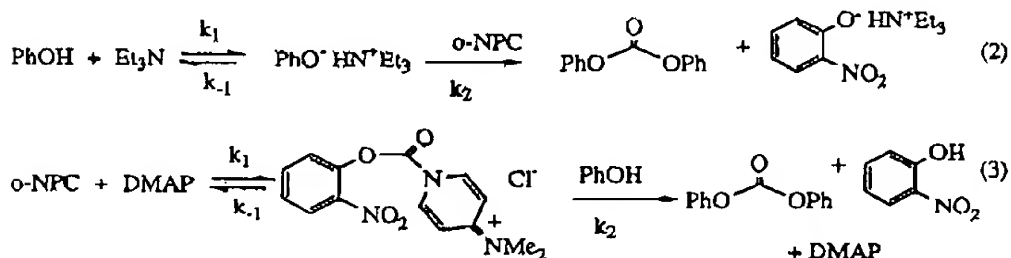
^ao-NPC and monomer used in equiv. amts. ^bHr/°C/lorr. ^cBy GPC relative to polystyrene stds.

Solventless reactions catalyzed by DMAP afforded high molecular weight polycarbonate at reaction temperatures of only 125° C. Further build of molecular weight was precluded due to the fact that the polymer is solid at that temperature. Solventless reaction was also possible using more conventional catalysis: reaction of bisphenol A with o-NPC in the presence of sodium phenoxide and a phase transfer catalyst provided polycarbonate with $M_n = 77,000$ at 200° C. All of the crude polymer products were yellow solids, due to the presence of o-nitrophenol. Dissolution into CH_2Cl_2 and precipitation with methanol gave white powders in all cases.

MECHANISM

The dissimilarity in the effect of DMAP catalysis in the transesterification reactions of *ortho*- and *para*-nitrophenyl carbonates is striking. Whereas an equivalent of triethylamine causes p-NPC to react about twice as fast as the *ortho* isomer, the use of 1% molar DMAP causes o-NPC to react 42 times faster than the *para* isomer. Furthermore, addition of 1.0 eq of Et₃N to a reaction of o-NPC catalyzed by 1% DMAP has no effect on the reaction, whereas similar addition to a p-NPC reaction affords a 17-fold rate increase. It seems clear that the intermediates involved are dissimilar. A pseudo-second order reaction for p-NPC is suggested by the fact that reaction requires a full equivalent of base. Rapid reaction of Et₃N with phenol followed by a slower reaction of phenoxide and carbonate provides first order dependence on phenol, Et₃N, and p-NPC. The reactions of o-NPC, in contrast, display pseudo-first order kinetics, with a linear rate dependence on catalyst and substrate, but not on phenol. Thus, k_2 of equation 3 will be greater than k_1 . The difference in reactivity of the *ortho*- and *para*-nitrophenyl carbonates using Et₃N can easily be rationalized based on steric effects and the lower leaving group ability of o-nitrophenol. The effects of DMAP catalysis are not so readily explained.

The most likely explanation for catalysis of o-NPC by DMAP is a very unusual stabilization of the tetrahedral intermediate formed by attack of DMAP. Stabilization of the delocalized cation by the proximity of the *ortho*-nitro group would lower the energy of this intermediate, thereby reducing the activation energy of the reaction. The fact that only amines which form delocalized acyl ammonium salts (DMAP, DBU, DBN, and N-methylimidazole) show this type of catalysis supports this hypothesis. Further supporting mechanistic work will be published in due course.



CONCLUSION

It has been demonstrated that o-NPC can be very useful for the preparation of aromatic carbonates and polycarbonates via transesterification. Although

phosgene is used for its preparation, the carbonate is indefinitely stable (years) under ambient conditions. *o*-NPC reacts readily with phenols and bisphenols using a catalytic amount of nucleophilic catalyst, differing markedly from *p*-NPC, which requires a full equivalent of base. High molecular weight polycarbonates have been prepared in solution and in the melt. The activation of *o*-NPC by DMAP is ascribed to a novel interaction of the *ortho*-nitro group with a π -delocalized ammonium ion in the tetrahedral intermediate.

EXPERIMENTAL SECTION

General. Proton NMR were recorded on a Varian EM-390 spectrometer and infrared on a Perkin-Elmer 457 spectrophotometer. VPC were carried out on a Varian 3700 gas chromatograph, using a 6-foot OV-17 column. Molecular weight determinations were carried out by GPC on a Dupont Instruments HPLC using Waters styragel columns and polystyrene standards. All reagents and solvents were reagent grade, used without purification, unless noted. *p*-NPC was purchased from Aldrich Chemical Co., and was recrystallized prior to use.

Bis-(*o*-nitrophenyl) carbonate. *o*-Nitrophenol (84.6 g; 0.60 mol) was dissolved in 1 L of CH_2Cl_2 and was treated with Et_3N (60.6 g; 0.60 mol), forming a bright orange solution. Phosgene/benzene solution (270 ml of 1.11 M; 0.30 mol) was added over 3 hrs. After cooling to 0°C , one liter of ether and 500 ml of water were added, causing the product to precipitate. The CH_2Cl_2 -ether solution was washed with 1 M HCl, 0.5 M NaOH, and water, and then² evaporated to yield additional product. Recrystallization from CHCl_3 /petroleum ether afforded 83.46 g of pale yellow crystals with mp = $104\text{--}106^\circ\text{C}$ (91.5%). The IR spectrum had C=O at 1792, N-O at 1531 and 1350, and C-O at $1200\text{--}1250\text{ cm}^{-1}$. ^1H NMR had a series of multiplets at 7.2–7.9 ppm and a doublet of doublets at 8.22 ppm for the aromatic proton *ortho* to the nitro group.

Transesterification Reactions: General Procedure. Nitrophenyl carbonate (304 mg; 1.00 mmol) and the appropriate phenol (2.0 mmol) were dissolved in CH_2Cl_2 at 0°C . The nitrophenyl carbonates are pale yellow-colored. Amine catalyst (see Tables 1 and 2 for appropriate amounts) was added, giving an instantaneous yellow solution in reactions involving *o*-NPC and DMAP. In reactions using Et_3N , the amine was added neat; in reactions involving DMAP, the catalyst was added as a 0.10 M solution in toluene. Aliquots were removed periodically and were quenched with 0.1 M *p*-toluenesulfonic acid before analysis by VPC. Analysis at 150°C using *n*-octadecane as an internal standard provided the results displayed in Figure 1 and in Table 1. For reactions in Table 2, the products were isolated after 2 hr at ambient temperature by washing with 0.1 M HCl, 0.5 M NaOH, then with water, drying and evaporating to afford product.

Polymerization Reactions. **A. Solution polymerization:** *o*-NPC (5.00 mmol; 1.521 g) and a bisphenol (5.00 mmol) were stirred in 20 ml of CH_2Cl_2 at ambient temperature with 0.1–0.5% DMAP for 20 hr. Most reactions² were heterogeneous at start of reaction, but slowly solubilized as free bisphenol was consumed. The yellow product solutions were poured into 200 ml of methanol to afford white powders in high yields in all cases. Tough, transparent Films of bisphenol A polycarbonate were cast from CHCl_3 .

B. Melt reactions: Equimolar amounts of bisphenol A and *o*-NPC were reacted with 0.2 mole % each of NaOPh and Bu_4NBr , heating at 150°C under nitrogen for 1 hr, followed by application of vacuum (10 mm) and warming to 200°C . The resultant yellow polymer was dissolved in CH_2Cl_2 , filtered, and precipitated into methanol.

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